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FINAL REPORT

STRAW CHOPPER SYSTEM FOR MANURE PIPELINES

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Date: March 2000
Tested at Humboldt
ADF #9700326

Final Report

Straw Chopper Systems for Manure Pipelines

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1. Summary

Research was done to find a device to chop the straw and other debris entering the inlet of a pipeline manure pump. Various chopping and pumping devices meant to work with high-solids slurry were investigated. A hydraulically driven chopper pump was selected, as it appeared to be the most appropriate. A pump was purchased, mounted on a frame and field tested. It worked well as a main pump priming unit and also was effective in pumping manure from a straw covered EMS.

2. Technical Report

2.1 Introduction

Pipeline manure handling systems are becoming popular for moving large amounts of manure from the manure storage to the field injector. They have the advantage of being able to handle large volumes of manure in a continuous flow manner with no municipal road damage. However, some units are collection of components from the irrigation industry, and therefore there are some components missing that would enhance the system operation. One of these is a device to chop straw and other debris before it entered the main manure pump. It would also be useful if this device aided in priming the main pump. If priming were simpler than the present hand pump method, main pump startup would be much simpler and quicker. Chopping the straw before it entered or plugged the main pump would make it more feasible to use these systems to move manure from an earthen manure storage (EMS) that has a straw cover for odour control.

This project was done to try to solve this problem by searching for an appropriate device, and if one was found, to test it in Saskatchewan conditions.

2.2 Objectives

The objectives of this project were to:

1) Search for a potentially appropriate device to chop straw and, if possible, prime the main manure pump.
2) Obtain and install the device and prepare it for field use.
3) Test the unit in Saskatchewan conditions.

2.3 General Description

The pipeline manure handling system used in this project was largely assembled from components from the irrigation industry. The main pump was a centrifugal pump driven by a stationary diesel engine. The pump inlet was a section of aluminum pipe placed into the Earthen Manure Storage (EMS). The pump outlet was attached to a section of flexible hose with a fitting on the outlet end for connection to standard 6 in. aluminum irrigation pipes. Several sections of these pipes were connected together to transport the manure from the EMS to the field. From there, two 660 ft. sections of flexible drag hose transported the manure to the distributor on a tractor drawn cultivator. A second tractor was needed to periodically reposition a metal "knuckle" that joined the two drag hose sections.

2.4 Project Scope

The first stage of this project involved a search for potential devices that would adequately perform one or both of the desired functions. Agricultural and other industries, such as municipal sewage, were investigated. The advantages and disadvantages of each device were assessed against a set of predetermined criteria, and the most promising unit was selected and purchased. This pump was then mounted on a frame and taken to the field for testing. It was tested first with manure that had no straw cover and then later used in an EMS with a straw cover.

2.5 Results and Discussion

2.5.1 Device Selection

Selection Criteria: Before the search for the various devices was initiated, a set of criteria was developed. It was hoped that the chosen unit would satisfy all criteria, but it was recognized that some compromises might be needed. The selection criteria were as follows:

1) The chopper must chop straw and other debris fine enough that it would not plug any of the hoses, pipes or other equipment used in moving or applying the manure.
2) It should serve as a priming unit for the main pump, and be capable of pumping the manure up to 70 ft. along the slope to a main pump on the shore of the EMS.
3) It should be driven by hydraulics or some other power source that is readily available at the EMS.
4) The chopper should be able to match or exceed the capacity of the main pump (about 600-800 US gpm).
5) It should match the existing piping sizes to allow ease of installation and incorporation into the system.
6) It should be economical, practical and easy to use.

Devices Investigated: Several devices from the agricultural and municipal sewage industry that are intended to chop and pump slurry with a high solids content were investigated. Below are descriptions of each and a discussion on their suitability to this project.

The Annihilator is made by Az Tech Comminutors Inc. from Clearwater, Florida. It consists of two vertical rotating cylinders with intermeshing teeth. This unit is designed to chop material at a pump inlet, and it appears that it would be very effective at this process. However, it would not provide any pumping action, and therefore would not serve to prime the main pump. It was also quite expensive and its electric drive was not practical for use in an EMS.

Barber Valve and Controls Ltd., from Regina, Saskatchewan, handles Viking equipment, which manufactures submersible sewage pumps. However, given the criteria for this situation, they could not supply a pump that they would warranty for this application.

Vaughan Co., Inc., from Montesano, Washington, manufactures a chopper pump that is designed to pump high solids slurry similar to what is in a standard EMS. However, its performance characteristics were more suited to a high pressure-low flowrate situation than the low pressure-high flowrate situation that was present for this project. It was also quite expensive.

The Barracuda, manufactured by Hydro Engineering Inc. from Young America, Minnesota, is a spiked cylinder that rotates within a housing that has stationary blades attached to the inside of the housing. This unit is mounted as an in-line unit and therefore could not be submerged in the EMS. It would probably chop any straw that got into the pump very well, but it would not solve the problem of straw bridging across the pipe inlet. It also did not provide any pumping action.

Balzer Mfg. Co., from Mountain Lake, Minnesota, manufactures a pre-chopper that is installed ahead of a standard portable agitator pump. This unit would also act as an agitator, but would not replace the present agitator pump that is being used. It was also tractor driven, which is feasible, but not as desirable as a hydraulic drive unit.

Liquid Waste Technology (LWT), from Somerset, Wisconsin, manufactures a chopper pump meant for use in hog manure. It is a small centrifugal pump with a modified inlet to chop any incoming straw or other debris (**Figure 2**). It is small and hydraulically driven, and its performance characteristics closely matched those of the main manure pump. Because of these reasons and its relative low cost, this pump was chosen and purchased for this project.

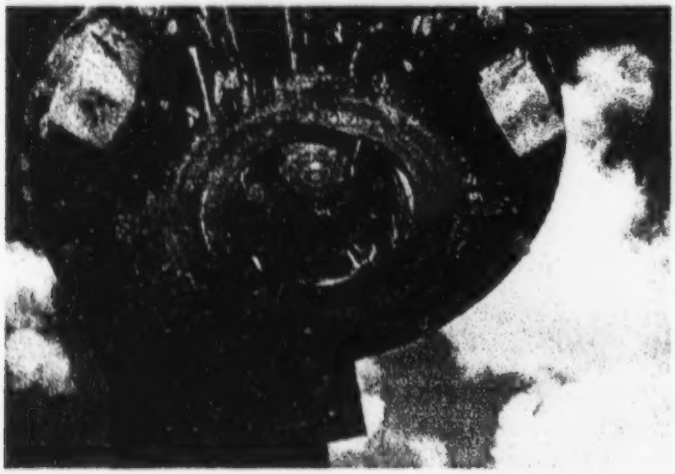

Figure 2. Chopper Pump Inlet.

2.5.2 Pump Assembly

An old manure pump was obtained for use as a frame for mounting the LWT pump. The pump body, agitator nozzle, and all other components were removed from the frame to leave only the bare frame, wheels and wheel height adjustment mechanism. The main frame of the manure pump was a piece of hollow, square tubing which previously housed the driveshaft for the original pump. For this project, the LWT pump was mounted on the end of the tubing with the pump outlet matched to the end of the tubing. Therefore, the tubing frame was used as the flow passage for the manure. An outlet with an appropriate irrigation fitting was fabricated as an outlet at the hitch end of the frame. All of the holes in the frame were plugged, and hydraulic hoses were routed along the frame for wheel position control and pump operation. Before these modifications the frame was extended by 10 ft. on both ends to make it 20 ft. longer than it originally was, to ensure that it could reach down the banks of a large EMS (**Figure 3**).

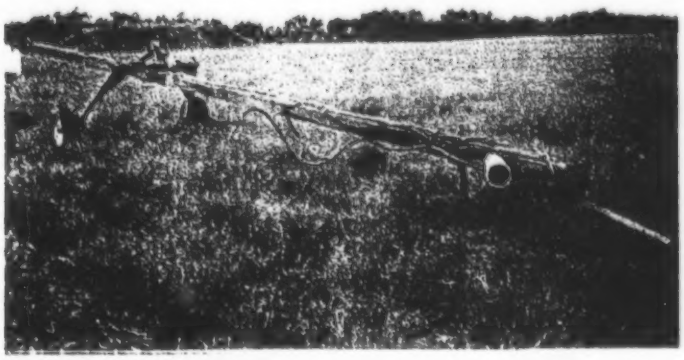

Figure 3. Chopper Pump.

2.5.3 Field Tests

Pump Operation: The LWT pump was operated for about 50 hours at Possberg Pork Farms and Big Sky Farms manure sites during the fall of 1998. In all cases, it was used to pump the manure from the EMS up to the main manure pump. For this application, it worked very well. Manure pumping personnel appreciated not having to prime the main pump, and they noticed that the main pump was not as noisy as when the LWT pump was not being used. This was likely due the main pump not having to draw the manure up from the EMS and therefore not working as hard. Centrifugal pumps are typically better at providing pressure than suction. The priming function may also have reduced pump cavitation. In one instance, the LWT pump plugged when a plastic part left over from barn construction became lodged in the inlet. The hose from the pump had to be disconnected and the pump removed from the lagoon by the tractor in order to

dislodge the piece of plastic with a crowbar. Because of weather limitations, there was no opportunity to use this pump in a straw covered EMS during this test season. This portion of the testing was completed in 1999.

The pump towed down the road well at up to 80 km/h, but travel speed had to be reduced on bumpy roads to reduce frame bouncing.

Pump Capacity:

Table 1. Pump Output Flow vs. Power.

Manure	Hydraulic Oil		Estimated Power*
Flow (USgpm)	Pressure (psi)	Flow (gpm)	Power (hp)
300	550	8.0	2.6
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1,006	1,850	16.5	17.8
1,080	2,100	18.0	22.0
1,205	2,500	19.5	28.4

* Values do not include pump or motor efficiency.

The main manure pump used in this system operates at about 500-600 US gpm at full capacity. To provide this flow, the LWT pump needs an input hydraulic pressure of 1000 psi and a flow of 11.5 gpm. This is well within the capabilities of most mid-sized tractors. At the maximum tractor operating pressure of 2,000 psi, the hydraulic oil flow was only 10 gpm, and this produced a manure flowrate of 1,080 US gpm. These pressure and flow requirements may increase when moving manure that has straw in it, but it appears that there is plenty of reserve capacity in this pump to absorb the change and provide an adequate manure supply to the main manure pump.

Straw Chopping: The chopper pump was used in an EMS with a straw cover in the summer of 1999. The manure flowrate and pressure were measured while pumping liquid only and when pumping liquid and straw pieces. The results from these tests are given in **Figure 4**.

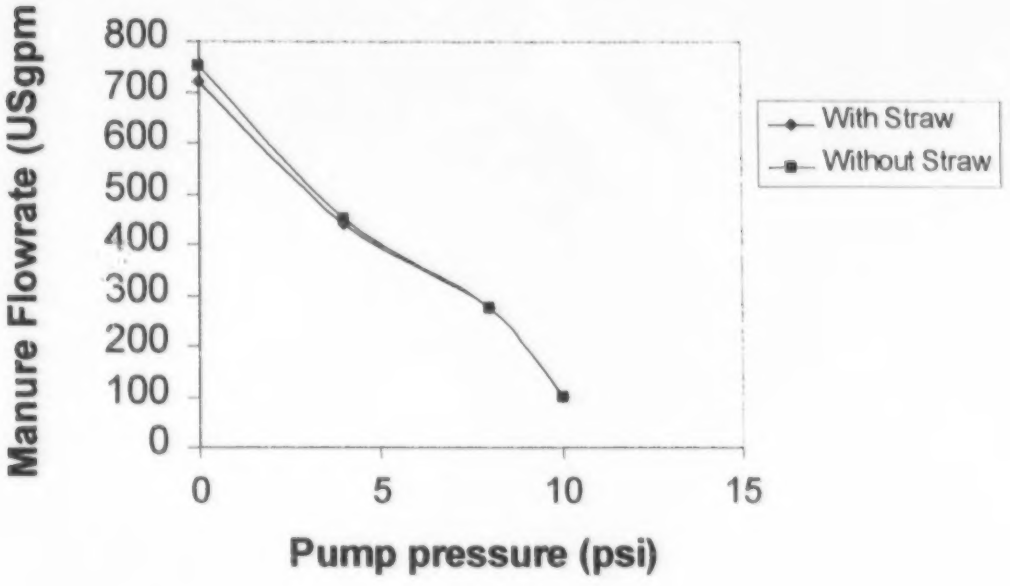

Figure 4. Chopper Pump Flow Tests.

Pumping straw had little effect on the pump output. The pump did not plug with straw, but there was occasionally some straw lodged in the pump inlet. This was easily cleared by removing some by hand and then reversing the pump direction while it was raised out of the liquid. The straw length entering the pump varied from about 4 to 12 in. long with an average at about 7 in. long. Most of the straws exiting the pump were 3 to 4 in. long, and some were as long as 12 in. This test could be considered a worst case, because if the EMS was pumped out during the fall, the straw would be more likely to be rotted and easier to break apart.

4. Equipment Purchased

A chopper pump was purchased from Liquid Waste Technologies for a price of $2,413.74 and incorporated into the chopper unit developed for this project.

5. Project Developed Materials

To date, no materials have been developed for this project. However, information from this report and several other reports will be included in a future PAMI Research Update.

6. Project Photos

Photos for this project are incorporated into the body of the report.

7. Acknowledgements

ADF funding will be acknowledged in all reports and at public demonstrations. This equipment was displayed during the Manure Management '99 tour in June 1999, at which time ADF funding was acknowledged. The equipment was also demonstrated to and used by personnel at four hog barns.

Appendix I

Efficient Injection for Sustainable Nutrient Management of Manure
(PAWBED #IAS-98L0-014)

Acknowledgements

The Prairie Agricultural Machinery Institute (PAMI) would like to acknowledge that primary funding for this project was provided by the Partnership Agreement on Water Based Economic Development. Related projects were funded by Saskatchewan Agriculture (Agriculture Development Fund). PAMI would also like to thank the administrative and manure pumping staff at Possberg Pork Farms and Big Sky Farms for their cooperation during this project.

Project No. RH0298
Date: March 2000
Tested at Humboldt

PAWBED #IAS-98LO-014

Final Report

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1. Introduction

Pipeline manure handling systems are becoming popular for moving large amounts of manure long distances from the manure storage to the manure injector. They have the advantage of being a continuous flow system (except for setup time) that can move large volumes of manure with no municipal road damage. However, some systems are largely an assembly of components from the irrigation industry that are not specifically suited for handling liquid manure. Some additional components are needed to tailor the system to manure handling to make the best use of manure as a crop nutrient source. It had been identified that some of the problems with the system included:

- A lack of a means to control the pumping unit from the injection unit so that flow could be shut off at headlands or when a leak occurred.
- No means of measuring application rate of manure or nutrients and no means to control it.
- Difficulties with plugging of irrigation style pumps with straw or refuse.

This project was done to investigate options for improvements to such pipeline manure handling systems based on irrigation equipment. A pipeline system developed by a local hog producer was used as a basis for experimentation and development and the final system as modified was employed to demonstrate the effectiveness of the new techniques. A remote control system was developed in a related project. The report for this project appears in **Appendix I**.

3. Objectives

The objectives of this project were to:

1) Investigate equipment improvements to the Possberg pipeline manure handling system.
2) Investigate the suitability of a conductivity meter for determination of manure nutrient value.
3) Demonstrate the application of liquid manure on a field scale and determine the crop response.

3. Summary and Conclusions

A straw chopping pump was obtained and tested in the field. It was capable of chopping the straw typically found on an EMS, and served well as a priming pump for the main manure pump. It was also easy to use and economical. An electromagnetic flowmeter was obtained and tested while pumping manure. It did not restrict manure flow and provided an accurate indication of manure flowrate and volume of manure pumped. Several methods of flow control were tested, and pump speed control was the most practical, if the pump motor was capable. If the pump was driven by an electric motor, then a combination of throttling and manure bypass could also be used to control manure flow. An in-line nutrient sensor was designed and tested. It showed some promise in determining manure ammonium level, but these tests did not confirm that it was suitable to be used as a part of a variable rate control system. A full-scale agronomic demonstration was done. The sections of the field treated with manure showed a significant crop response to both application rates.

4. General Description

The pipeline manure handling system used in this project was largely assembled from components from the irrigation industry. The main pump was a centrifugal pump driven by a stationary diesel engine. The pump inlet was a section of aluminum pipe placed into the Earthen Manure Storage (EMS). The pump outlet was attached to a section of flexible hose with a fitting on the outlet end for connection to standard 6 in. aluminum irrigation pipes. Many of these pipe sections were connected together to transport the manure from the EMS to the field. In the field, two 1,320 ft. sections of flexible drag hose transported the manure to the distributor on a tractor drawn cultivator (**Figure 1**). A second tractor was needed to periodically reposition a metal "knuckle" that joined the two drag hose sections.

During the course of this project, several different components, such as valves, meters, etc., were added to this system. Descriptions of these components will be discussed in each appropriate section of the report.

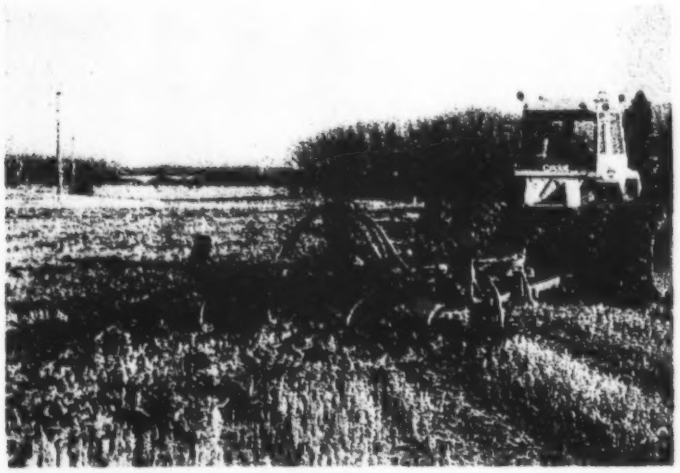

Figure 1. Pipeline Manure Injector.

5. Project Scope

The first stage of this project involved equipment selection. Equipment for straw chopping, flowmeters, and flow control components were all investigated. The operating characteristics of all components were determined and assessed for their application in the given situation. Components were then selected and tested in the fall of 1998 and spring of 1999.

A 4EC conductivity sensor was designed and built by the Agricultural and Bioresource Engineering Department at the University of Saskatchewan. The sensor was calibrated and used during the manure pumping season in the fall of 1998. Further testing was done in the fall of 1999.

During the fall of 1998, two manure plots had manure applied at two application rates. The land was seeded in 1999, and crop response monitored during the growing season. Yield was measured during the harvest. The sites were included in manure management tours in the area.

6. Results and Discussion

6.1 Straw Chopping

6.1.1 Device Selection

Before the search for the various devices was initiated, a set of criteria was developed. It was hoped that the chosen unit would satisfy all criteria, but it was recognized that some compromises might be needed. The selection criteria were as follows:

7) The chopper must chop straw and other debris fine enough that it would not plug any of the hoses, pipes or other equipment used in moving or applying the manure.
8) It should serve as a priming unit for the main pump, and be capable of pumping the manure up to 70 ft. along the slope to a main pump on the shore of the EMS.
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6.1.2 Devices Investigated

Several devices from the agricultural and municipal sewage industry that are intended to chop and pump slurry with a high solids content were investigated. Below are descriptions of each and a discussion on their suitability to this project.

The Annihilator is made by Az Tech Comminutors Inc. from Clearwater, Florida. It consists of two vertical rotating cylinders with intermeshing teeth. This unit is designed to chop material at a pump inlet, and it appears that it would be very effective at this process. However, it would not provide any pumping action, and therefore would not serve to prime the main pump. It was also quite expensive and its electric drive was not practical for use in an EMS.

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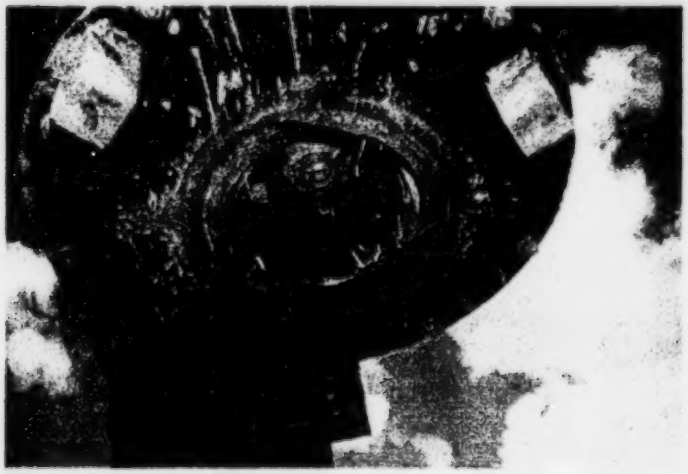

Figure 2. Chopper Pump Inlet.

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Figure 3. Chopper Pump.

6.1.3 Field Tests

Pump Operation: The LWT pump was operated for about 50 hours at Possberg Pork Farms and Big Sky Farms manure sites during the fall of 1998. In all cases, it was used to pump the manure from the EMS up to the main manure pump. For this application, it worked very well. Manure pumping personnel appreciated not having to prime the main pump, and they noticed that the main pump was not as noisy as when the LWT pump was not being used. This was likely due the main pump not having to draw the manure up from the EMS and therefore not working as hard. Centrifugal pumps are typically better at providing pressure than suction. The priming function may also have reduced pump cavitation. In one instance, the LWT pump plugged when a plastic part left over from barn construction became lodged in the inlet. The hose from the pump had to be disconnected and the pump removed from the lagoon by the tractor in order to

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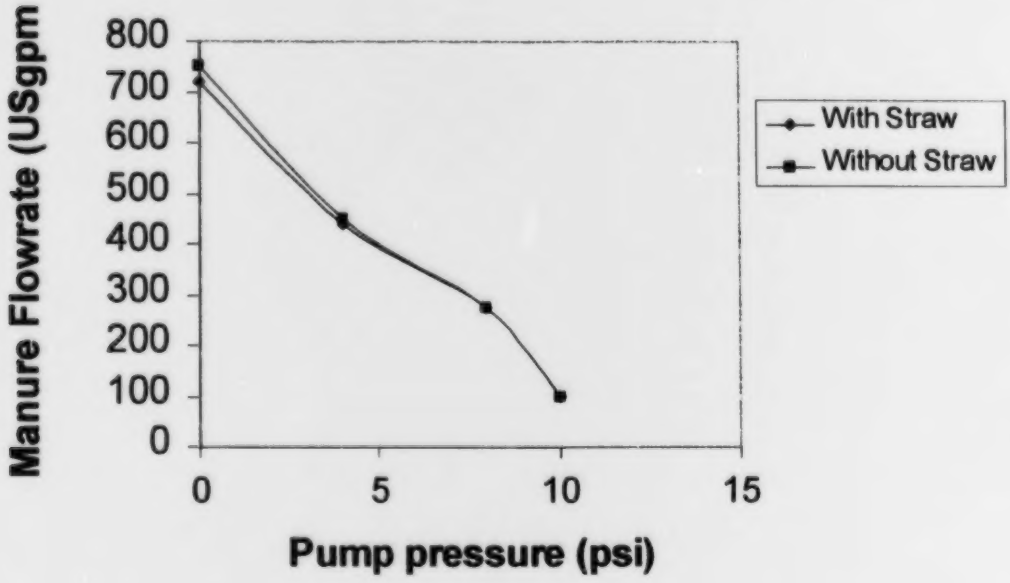

Figure 4. Chopper Pump Flow Tests.

Pumping straw had little effect on the pump output. The pump did not plug with straw, but there was occasionally some straw lodged in the pump inlet. This was easily cleared by removing some by hand and then reversing the pump direction while it was raised out of the liquid. The straw length entering the pump varied from about 4 to 12 in. long with an average at about 7 in. long. Most of the straws exiting the pump were 3 to 4 in. long, and some were as long as 12 in. This test could be considered a worst case, because if the EMS was pumped out during the fall, the straw would be more likely to be rotted and easier to break apart.

6.2 Flowmeter

6.2.1 Device Selection

Measuring the flowrate of liquid hog manure is not easy, as it is very inconsistent and corrosive. There are many types of flowmeters available with different operating principles. Choosing the most appropriate type of flowmeter for this application involved assessing each type against a set of criteria. A flowmeter that would adequately measure manure flowrate had to have the following characteristics.

1) Corrosion resistant
2) No internal obstructions for solids hang-up
3) Work well with 0 to 20% solids
4) Work with varying fluid characteristics
5) 12V DC power supply
6) Suitable for outside installation

Many types of flowmeters were considered and dismissed almost immediately because certain characteristics made them unsuitable for this application. Many flowmeters are available that use a propeller or metering wheel to sense the velocity of the fluid in a pipe. The propeller or wheel protruding into the path would likely plug up with solids, so these types of meters were not considered any further. This same reasoning was used to discount vortex shedding and venturi type flowmeters, as they both have an obstruction in the flow path. Doppler flow meters mount outside pipes and measure the velocity of particles or bubbles in the fluid, but they do not work well with varying fluid characteristics. Coriolis flowmeters would probably work in the application, but none could be found that were large enough.

The type of flowmeter chosen for this project was an electromagnetic flowmeter. These units set up a magnetic field in the fluid. Voltage is induced by the movement of the fluid through the meter. This voltage is proportional to the mean fluid velocity and is unaffected by the fluid characteristics. These meters only have two very small electrodes in the flow path, so they offer almost no obstruction to the fluid flow. The meter chosen for this project had a Teflon insert for corrosion resistance and was powered by 12V DC. The flowmeter suppliers all suggested this type of flowmeter would be most likely to work in this application with the desired accuracy.

6.2.2 Field Tests

A Krohne model FM4010K electromagnetic flowmeter was obtained for these tests. It was installed in line between the manure pump outlet and the main pipeline (**Figure 5**). During the entire season it functioned well. The operators found it very useful to know the actual manure flowrate. This flowmeter also calculated the total volume of fluid passed through the meter. Recording this value at the start and end of pumping a given EMS would give the total volume pumped out of the EMS. The operators found this to be a useful feature.

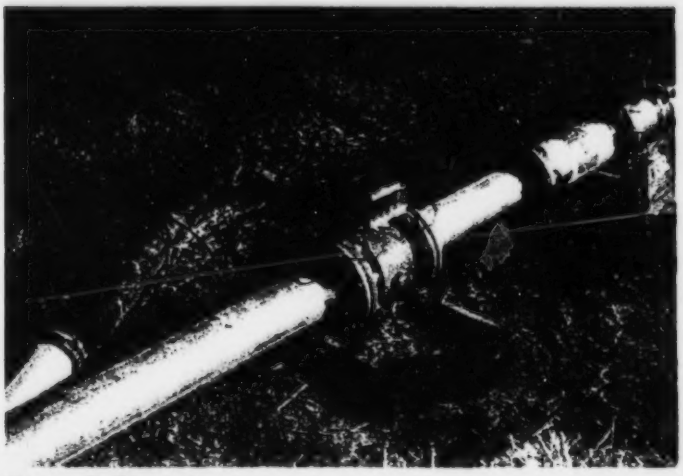

Figure 5. Flowmeter.

The flowmeter was provided with a calibration certificate claiming accuracy from –0.21% to +0.36%. Tests were done to confirm this claim. The total volume from the flowmeter display was recorded. The liquid level and surface area of one cell of an EMS were also recorded using land surveying equipment. Manure was then pumped through the flowmeter from this cell to a different cell of the same EMS. The volume from the flowmeter was again recorded along with the EMS level and surface area. The manure volume was calculated from the two EMS levels and area and compared to the difference of the values recorded from the flowmeter. This process was done twice in the same EMS. The results are given in **Table 2**.

Table 2. Flowmeter Accuracy Test Results.

Trial	Flowmeter Volume (US gallon)	Surveyed Volume (US gallon)	Difference (%)
1	556.2	547.9	1.5
2	1,032.8	1,023.8	0.8

The differences from these tests are higher than claimed on the calibration certificate but are well within the accuracy needed for field testing and application. It is very probable that the methods used to measure volume for the factory calibration were more accurate than the method used in the field for this project. In any case, it appears that this type of flowmeter works well for measuring manure flowrate under field conditions.

6.3 Flow Control

6.3.1 Component Setup

Most pipeline manure systems have no specific method to control flowrate and are therefore operated at full capacity at all times. This type of operating procedure works but there is very little control of the application rate. Methods for controlling the flowrate in an attempt to control the application rate were investigated in this project.

The three methods to control flowrate that were investigated in this project were engine speed control, manure flow throttling and manure flow bypass. Engine speed control involved changing the engine speed and therefore the manure pump speed. Manure flow throttling involves using a valve to restrict the manure flow in the pipeline just after the manure pump while maintaining all other settings. Manure flow bypass was done by partially opening a valve that allowed some of the manure flow to return to the EMS, thereby reducing the amount that went to the injector cultivator.

There was no equipment needed for controlling the flowrate using engine speed, as it only involved changing the engine throttle setting. Choosing a valve for manure throttling and manure flow bypass was more involved, as there are many valve types available. This project was done in conjunction with another project involving remote control of the manure flow, so choosing the valves for both projects was combined. The results of this search are described below.

Three types of valves were immediately discarded for manure bypass because they would almost certainly plug with straw or other solid material. These three types include gate valves, globe valves and butterfly valves. Gate valves are used on some manually operated manure handling systems, but suppliers warned that they may be prone to even partial plugging, and therefore may not work consistently enough to be used in an automatic control system. Pinch valves are simply a section of flexible hose that is pinched to shut off the flow, but they are not recommended for use as a throttling valve where there is no downstream pressure. Because of their simplicity, they do work well for isolating parts of the fluid handling system. In this situation they would be prone to cavitation and a shortened life. Ball valves have no restrictions when completely open,

and would probably work well for this situation. However, none that were available from local suppliers were of the correct size and made of the correct materials.

A plug valve consists of a housing that contains a plug that rotates through 90° from open to closed. When open, there is no restriction to flow, and as the valve closes there is a wiping action that helps to dislodge any solids that may have been caught in the mechanism while operating. This type of valve is also quite easy to mechanically actuate, as there is only a 90° movement from open to closed, as opposed to other valve types that require several handle turns. This type of actuation lends itself to simple monitoring of valve position. For these reasons, a plug valve was chosen for the bypass valve at the EMS (**Figure 6**). A gate valve was already present on the cultivator, so it was used to control the manure flow at the cultivator for this project. A pinch valve was obtained and installed on shore next the EMS just before the irrigation pipe that conveyed the manure to the field. This valve was installed to isolate the bulk of the manure piping from the pump, valves and other components used for this project. This made changing components more convenient, as the entire system didn't have to be drained each time the system was shut down. This valve was also used for the manure throttling tests, as it was available and served the intended purpose for this project. The previously mentioned cavitation problem was not seen to be a large concern as the test would only be for a short time period.

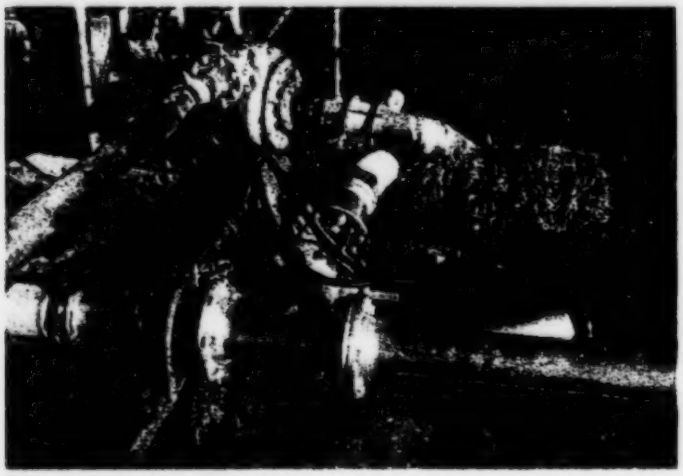

Figure 6. Bypass Plumbing.

A schematic of the plumbing assembly is shown in **Figure 7**.

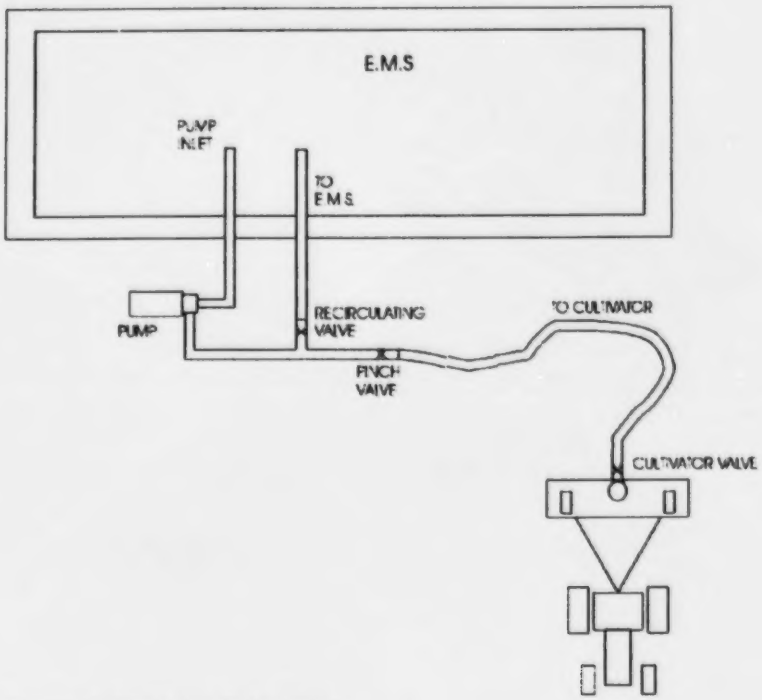

Figure 7. Plumbing Schematic.

6.3.2 Test Results

The tests involved changing the manure flowrate using all three methods while measuring flowrate and pressure and making other observations.

Results from the engine speed control are given in **Table 3**.

Table 3. Engine Speed Control Results.

Engine Speed (rpm)	Manure Flowrate (US gpm)	Manure Pressure (psi)
1,967	800	130
1,393	553	90

The manure flow could be varied from 800 to 553 US gpm by reducing engine speed from 1,967 to 1,393 rpm. At 553 US gpm, it was noted that the flexible drag hose behind the cultivator was becoming softer because the pressure was reduced to 90 psi. This made the hose more prone to kinking during turns, which could cause a pressure surge in the pipe from the sudden halt in the velocity. This in turn could cause hose or coupler failures. When the hose did kink, it usually resulted in a significant amount of

downtime, as the hose must be drained and straightened before manure will flow through it properly. Therefore, it is not recommended to operate this pipeline system with a manure pressure of less than 90 psi in this type of flexible drag hose.

The pinch valve was used for throttling the manure flow. Results from these tests are given in **Table 4**.

Table 4. Manure Throttling Results.

Manure Flowrate (US gpm)	Manure Pressure* (psi)
800	130
760	135
646	145
612	150
555	155

* Measured upstream of throttling valve.

As the manure flowrate was decreasing, the pump engine did not appear to be working any harder than at full flow. It was also noted during these tests that the draft hose was getting soft at 555 US gpm. This method can be used to reduce the manure flowrate, but the higher pressures noted upstream of the throttling valve may result in more leaks and component damage than if operating at lower pressures. This method is also not as efficient as reducing engine speed, as energy is wasted in the throttling process.

Manure bypass test results are given in **Table 5**.

Table 5. Manure Bypass Results.

Bypass Valve Position (0-13)	Manure Flowrate (US gpm)	Manure Pressure (psi)
Closed	800	130
1	750	120
2	675	110
3	558	90
3.5	500	70

Pressure and flow results from these tests were similar to other tests. The drag hose was getting soft at 90 psi and was thought to be too soft at 70 psi. An interesting note is that the bypass valve only had to be opened to an indicator position of 3.5 on a scale of 0-13 to achieve the lowest flowrate practical without hose kinking.

This method of flow control worked as well as the other methods. However, it was not as efficient as engine speed control since the excess flow from the pump was being returned to the EMS.

It appears that the most efficient and effective method for manure flow control is to simply reduce the engine (and therefore pump) speed. This method will work well provided the manure pressure in the drag hose is 90 psi or higher. If the flow must be reduced lower, then the manure flow could be throttled at the cultivator. Bypassing some manure flow back to the EMS could be used if throttling the manure at the cultivator would cause excess manure pressure. This would be the case if the pump was driven by an electric motor or other power source that did not allow simple speed change. Using a more rigid drag hose could allow for more reduction in feed pressure and lower flow volumes.

All of the above results are an attempt to change application rate by maintaining tractor and cultivator ground speed and changing manure flowrate. Another method to change application rate that could be considered is changing ground speed. However, there are other factors, such as tractor power, drag hose wear life and total pump out time that also must be considered.

Another factor that must be considered when changing manure flowrate is that there are solids in the manure and they may tend to settle out of the liquids if the manure velocity in the pipe drops too low. This could eventually plug the pipe. Determining the exact conditions that would cause solids settling would be a very involved procedure, as many factors are involved, such as pipe diameter, solids content, terrain and changes in flowrate.

6.4 In-Line Nutrient Sensing

6.4.1 Sensor Construction

The sensor for this project was designed and built by the Department of Agricultural and Bioresource Engineering (ABE) from the University of Saskatchewan. The sensor design is based on the 4EC concept, which has been used to measure soil conductivity. This type of sensor uses four electrodes and some associated electronics to measure the electrical conductivity of the substance it is in contact with. In this case, a section of 6 in. diameter PVC pipe was used on the frame, and four stainless steel rings were mounted inside the pipe to serve as electrodes. A Type T thermocouple was used to measure fluid temperature (**Figure 8**). A battery operated, sinusoidal function generator provided a signal to the two outer electrodes. A true RMS multimeter was used to measure the voltage across the function generator, the two inner electrodes,

and a 1KΩ resistor. The values obtained were used to calculate the electrical conductivity of the fluid in the sensor.

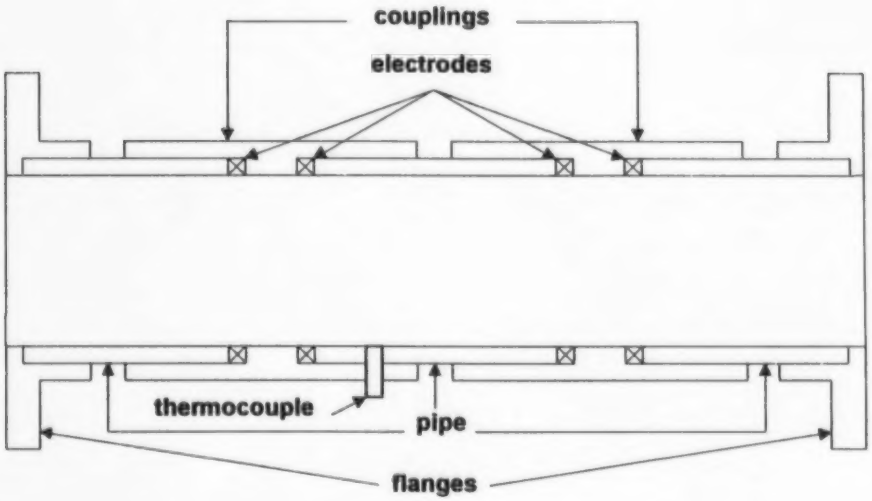

Figure 8. Nutrient Sensor Schematic.

6.4.2 Lab Tests

Preliminary lab tests were done by ABE to determine if the sensor was working as expected. Different concentrations of salt water solution were placed in the sensor and the sensor reading taken. The EC was also determined using a handheld EC meter. The results of these tests are given in **Figure 9**.

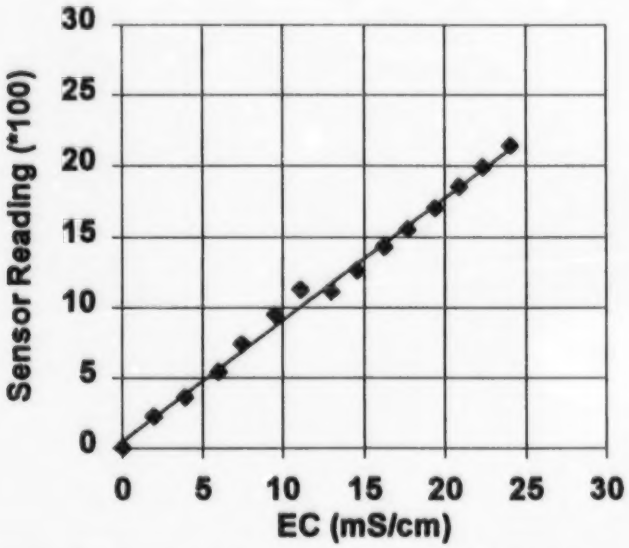

Figure 9. Sensor Readings with Salt Water Solutions.

The equation of the above line is:

Sensor reading = 0.0086 (EC reading) + 0.0047

and the coefficient of determination (R^2) is greater than 0.99.

This data shows that the sensor was responding well to changes in electrical conductivity. Similar tests were done with pig manure. The manure was placed in the sensor, EC and sensor readings taken, and then the manure diluted and the readings taken again. This was repeated several times. The resulting relationship was:

Sensor reading = 0.0045 (EC reading) + 0.086

with a R^2 of 0.66.

This correlation was not as good as the saline correlation, but was responding to changes in manure concentration. The sensor was then taken to an EMS for field tests.

6.4.3 Field Tests

The first set of field tests was to determine if the sensor reading was affected by manure flow. The sensor was installed in the manure pipeline at the shore of the EMS (**Figure 10**). While pumping manure through the sensor, readings were taken. The flow was varied in several steps from full to zero flow and readings taken at each flow. This process was repeated while drawing manure from the top, middle, and bottom of the EMS. Results are given in **Figure 11**.

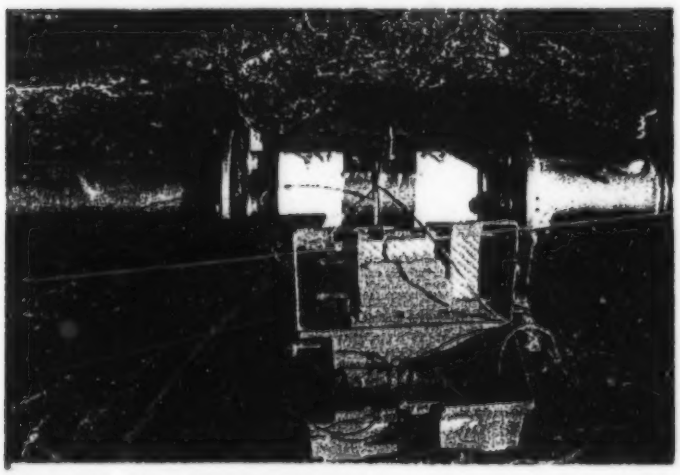

Figure 10. Inline Nutrient Sensor.

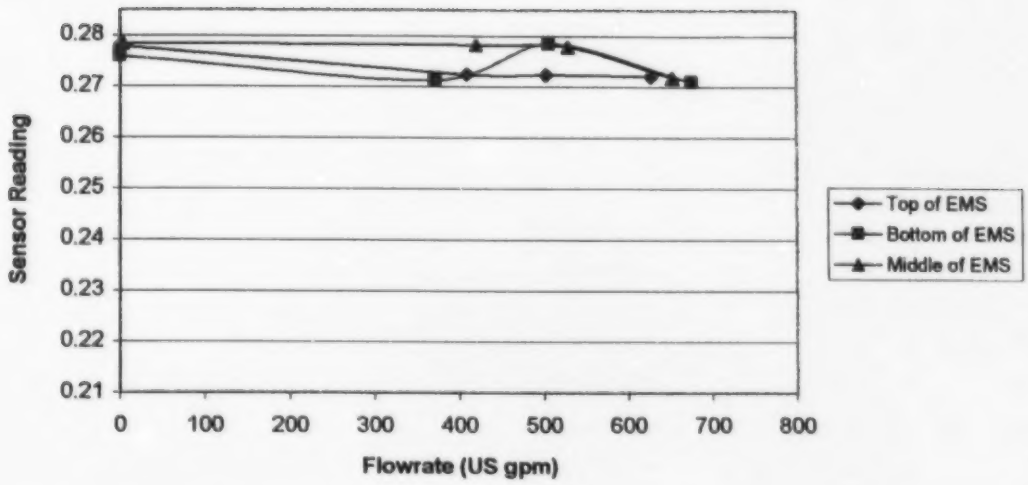

Figure 11. Flowrate vs. Sensor Reading.

From the above results, it appears that manure flowrate has little or no affect on the sensor reading. This increases the ease of operation of the sensor, as flowrate doesn't have to be considered as a variable. It also makes further testing easier and more reliable, as the manure can simply be placed in the sensor and readings taken. Because the manure will not be flowing, there is no risk that it is changing while readings are being taken.

The next set of testing involved noting the sensor readings with manure samples from different barns. Because flowing manure was not a requirement, all future tests were done by collecting a manure sample and simply placing it in the sensor. Manure was collected from five different barns with different types of animals. Sensor readings were taken with the manure at full strength and at several stages of dilution.

These readings were compared to the ammonium content in the manure as determined by a manure nutrient testing laboratory. For the diluted samples, the resulting ammonium content was calculated from the full strength manure sample analysis and the amount of water added during the diluting. Results of these tests are given in **Figure 12**.

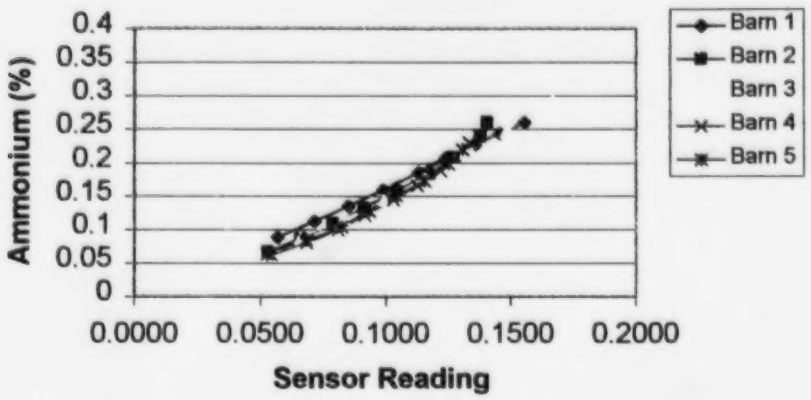

Figure 12. Ammonium vs. Sensor Readings.

The above results show that even though the manure samples were taken from several different barns, they all responded similarly to dilution. As the manure was diluted, the sensor reading decreased along with the ammonium content. Even though all of the samples were collected from different barns, they all responded similarly. This was promising, so further analysis was done on these samples.

The meter readings of the undiluted manure were compared to the ammonium contents for all five barns. The results are given in **Figure 13**.

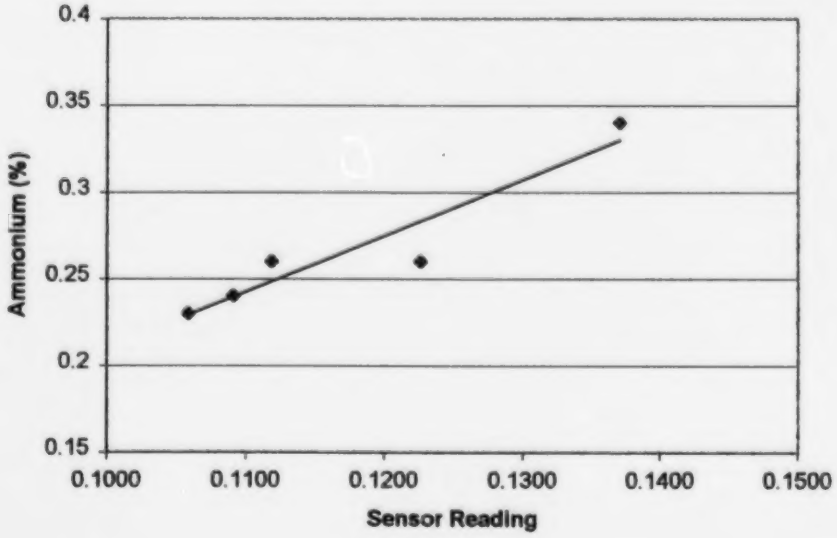

Figure 13. Undiluted Manure Comparison.

As the ammonium content increased, the meter reading also increased. The equation of this relationship is:

Ammonium content = sensor reading * 3.2303 – 0.113
and the R^2 for this data is 0.897.

This is quite a good fit and suggests that a reliable relationship exists between ammonium content and the output from this sensor. Whether or not this relationship is reliable and accurate enough to control the manure application rate can only be determined by further investigation.

It is possible that some of the variation between barns could be due to the background EC of the water used in the barn. To test this possibility, samples of the water from each barn were placed in the sensor and the sensor reading recorded. This reading was then simply subtracted from the sensor reading with the manure and the results plotted. Although more complex analysis methods may yield a more accurate result, this method was used as an indicator to determine if further analysis is warranted. After subtracting the water sensor readings, the relationship between ammonium content and sensor reading was worse, with an R^2 of only 0.4791. It appears that according to the data from these tests, it is better to not consider the background EC from the water supply when using this sensor to determine ammonium levels.

The ultimate goal of this sensor would be to use its output to indicate any changes in ammonium during manure pump out and use this indication to control the manure application rate. To assess this possibility, manure samples were collected during an entire EMS pump out. These samples were placed in the sensor, the readings taken, and then the ammonium levels determined. The results of these tests are shown in **Table 6**.

Table 6. Manure Analysis during Pump Out.

Pump Time (hrs)	0	2.5	3.5	6.5	9.5	12.5
Sensor Reading	0.142	0.140	0.127	0.146	0.142	0.137
Ammonium Content (%)	0.15	0.18	0.18	0.20	0.21	0.20
Lab Conductivity (mS/cm)	15	15	15	16	15	16

After 2.5 hours of pumping time, the ammonium content did not change much. However, the sensor reading did change during the course of pump out, which may suggest that in this case, the sensor reading was not related to the ammonium content. It should also be noted that the conductivity as determined by the manure testing laboratory changed only a small amount during pump out, and not in any trend that resembled the change in ammonium content.

From all of the above test results, it appears that in some cases, this sensor can be used to indicate changes in manure ammonium content. However, the one test done during an EMS pump out did not show much promise for this being used as a part of a variable rate control system. Based on these results, the same could be said about the whole concept of measuring the electrical conductivity of manure. It appears that there are more manure constituents than ammonium in manure that affect the EC in manure. It is also possible that measuring other manure properties along with EC may yield better correlation with nutrient content. It should be noted that this conclusion is based on only one test, and the ammonium content didn't vary much during the test.

An interesting observation from the above data is that after initial agitation, the ammonium level was fairly constant, as the manure was being continuously agitated during pump out. This suggests that an alternate operating strategy may be to agitate the manure well and keep agitating throughout pump out, and therefore, a reasonably homogenous material will be transported to the field. Perhaps a few manure samples could be collected each year and analysis done on each to get an idea of the average nutrient content of the manure from any particular barn. If the nutrient content showed some trend that was fairly predictable, this value could be used in determining the nutrient value of the manure in any given year before pump out began. This whole process would depend upon methodical manure sampling and agitation. However, if further research showed this was a viable procedure, effective application of manure nutrients could be made more simple and reliable, and therefore more readily practiced by barn operators.

6.5 Field Scale Agronomic Demonstration

In the fall of 1998, manure was applied to two field scale plots on land adjacent to the Big Sky Farms nursery barn. The land was sandy loam and had never had pig manure applied to it. The plots were 80 ft. wide and about 1,000 ft. long, with a 20 ft. wide untreated strip between them. The manure was applied from the EMS using the pipeline system. Using the flow meter to measure manure flowrate and the tractor ground speed, the two calculated application rates were 10,696 gal/ac and 22,509 gal/ac. The application rate was changed by varying tractor ground speed.

The land was seeded with Excel 6-row malting barley in early May of 1999 and no other commercial fertilizer was used.

During the growing season, both plots showed a marked difference in crop color and height compared to the untreated strip (**Figure 14**).

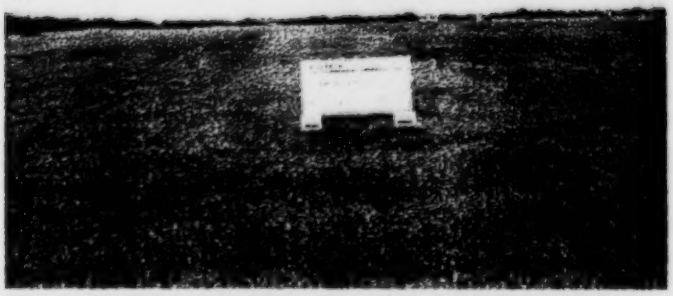

Figure 14. Field plots (High rate on left, low rate on right).

This difference continued throughout the growing season until harvest (**Figure 15**).

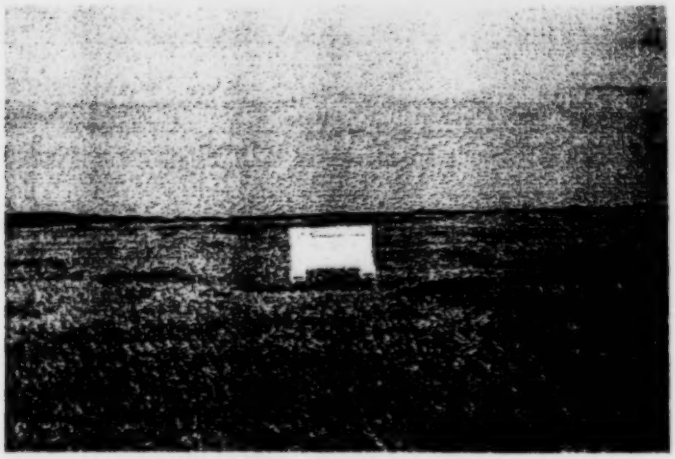

Figure 15. Field Plots Before Harvest.

During harvest, the yield from both plots and the untreated strip were obtained by weighing the grain harvested from measured sections of swath. The results are given in **Table 7**.

Table 7. Yield Results.

Manure Application Rate (gal/ac)	Yield (bu/ac)	Yield Increase (%)
0	45.3	0
10,696	65.1	43.7
22,509	66.8	47.5

In this case, adding manure resulted in a 43.7% increase for the low application rate and 47.5% increase for the high application rate. This is a significant increase and reaffirms that manure is a valuable fertilizer resource. There was not much difference in the crop yield response between the two rates, indicating that the crop had all the nutrients it needed (and possibly more) at the low application rate. The added nutrients would have to be available in future years to fully realize all of the fertilizer value in the manure.

Appendix I

Development of a Hog Manure Pipeline Control System
(ADF Project #97000074)

Project No. RH0797
Date: October 1999
Revised: February 2000
Tested at Humboldt

ADF NO. 97000074

Final Report

Development of a Hog Manure Pipeline Control System

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Acknowledgements

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1. Introduction

Pipeline manure handling systems are becoming popular for moving large amounts of manure from the manure storage to the field injector. They have the advantage of being able to handle large volumes of manure in a continuous flow manner with no municipal road damage. However, some units are largely a system assembled from irrigation components, and therefore there are some components missing that would enhance the system operation. One of these components is a system to turn the manure flow on and off from the injector tractor. This would be a useful feature as the cultivator is lifted out of the ground when turning around at the ends of the field, and it would prevent manure from being spilled on the soil surface. The system could also be used to shut off the manure flow in the case of a line break or other malfunction.

This project was carried out to try to solve these problems by developing and testing a prototype on/off device for a pipeline manure handling system.

2. Objectives

The objectives of this project were to:

1) Develop a system to turn the manure flow on and off in a pipeline manure system using remote control.
2) Test the system during a typical manure pumping season.

3. Summary and Conclusions

A system to remotely control the starting and stopping of manure flow in a manure pipeline injection system was developed. A preliminary design was done to determine system parameters and various control components were selected. The system was assembled and initial testing was carried out. A control strategy was developed that would provide satisfactory operation, adequate system protection, and flexibility to allow adjustment of the system operation during testing.

Initial tests were done with no manure flow and some programming changes were completed. After the initial tests, full-scale tests were done and after some adjustment, the system operated well. Some problems occurred during operation but were addressed and the changes were lab tested.

4. General Description

The pipeline manure handling system used in this project was largely assembled from components from the irrigation industry. The main pump was a centrifugal pump driven by a stationary diesel engine. The pump inlet was a section of aluminum pipe placed into the Earthen Manure Storage (EMS). The pump outlet was attached to a section of flexible hose with a fitting on the outlet end for connection to standard 6 in. aluminum irrigation pipes. Many of these pipe sections were connected together to transport the manure from the EMS to the field. In the field, two 1,320 ft. sections of flexible drag hose transported the manure to the distributor on a tractor drawn cultivator. A second tractor was needed to periodically reposition a metal "knuckle" that joined the two drag hose sections.

5. Project Scope

The first stages of this project involved preliminary system design. The needed plumbing layout was determined, and a control strategy was determined. Control component characteristics were also determined. Components were then selected, including valves, radio controls, and safety devices to protect the controls and the pipeline. The system was then assembled and preliminary tests done. In the field, the system was tested and refined and finally some auxiliary laboratory testing was also carried out.

Commercialization of the system will be attempted y the electronics contractor with assistance from PAMI by way of PAMI issuing a Research Update and presenting the project to the public at appropriate events.

6. Results and Discussion

6.1 Preliminary Design

Before detailed design was done on the system, some basic operating parameters were determined. It was assumed that simply turning off the manure flow at the cultivator would not work, as it could cause several problems including water hammer (shock waves set up in the liquid caused by rapid fluid acceleration or deceleration), which could overpressure the manure hoses and pipes, and damage the pump from rapid flowrate changes. It was therefore decided to not only turn off the manure flow at the cultivator, but also to simultaneously open a valve at the EMS to recirculate the manure flow back into the EMS. Coordinating the opening and closing of these two valves would be the challenge, as it would be preferable to have the on or off sequence happen as quickly as possible without introducing water hammer or other potentially damaging situations. A small programmable computer with associated electronics was chosen to control the valve opening and closing. Radio modems connected to the electronics both at the EMS and on the tractor cab would provide for communication between both locations.

Other system components had certain requirements placed on them because of the operating environment and operations they would be performing. The valves had to handle manure solids without plugging or manure buildup, as well as being resistant to the corrosive nature of hog manure. All other components had to work in a wet, corrosive environment. The radio control system between the tractor and EMS needed to work reliably with a range of at least two miles in less than ideal terrain and not cause or be subject to electrical interference from normal tractor operation or standard communication radios or cellular phones.

6.2 Component Selection

6.2.1 Valve Selection

Many types of valves were considered for this system. The advantages and disadvantages of all considered are described below.

Three types of valves were immediately discarded because they would almost certainly plug with straws or other solid material. These three types include gate valves, globe valves and butterfly valves. Gate valves are used on some manually operated manure handling systems, but suppliers warned that they may be prone to even partial plugging, and therefore may not work consistently enough to be used in an automatic control system. Pinch valves are simply a section of flexible hose that is pinched to shut

off the flow, but they are not recommended for use as a throttling valve where there is no downstream pressure. In this situation they would be prone to cavitation and a shortened life. Ball valves have no restrictions when completely open, and would probably work well for this situation. However, none that were available from local suppliers were of the correct size and made of the correct materials.

A plug valve consists of a housing that contains a plug that rotates through 90 degrees from open to closed. When open, there is no restriction to flow, and as the valve closes there is a wiping action that helps to dislodge any solids that may have been caught in the mechanism while operating. This type of valve is also quite easy to mechanically actuate, as there is only a 90 degree movement from open to closed, as opposed to other valve types that require several handle turns. This type of actuation lends itself to simple monitoring of valve position. For these reasons, a plug valve was chosen for the recirculating valve at the EMS. A gate valve was already present on the cultivator, so it was used to control the manure flow at the cultivator for this project.

6.2.2 Actuator Selection

Calculations were done to determine probable valve opening and closing times that would be quick enough to be practical and would not cause water hammer. Equations developed for the irrigation industry were used for these calculations. These equations consider the compressibility and density of water, pipe diameter, pipe material elasticity and pipe wall thickness to calculate the pressure wave velocity and subsequent instantaneous pressures. The worst case scenario for this project was found to be a valve closing time of 20 seconds. This was thought to be quite long, so the system was designed so the opening and closing of the valves could be changed from 20 seconds to about 2 seconds. This decision affected the actuator selection.

The available methods of valve actuation included electric, compressed air, or hydraulic. Because compressed air was not available at the tractor or the EMS, it was discarded immediately. Electric actuators were available for the plug valve at the EMS, but because this was a large valve, their opening times were several minutes long, which was not acceptable. The speed of these actuators was also not variable, which did not fit this project either. Another option was a factory installed air operated actuator. Because compressed air was not available, we decided to use hydraulic pressure to move the actuator. This would require a pressure reducing valve to reduce

the hydraulic pressure from the standard 2,000 psi available from most tractors to 100 psi. By using hydraulics, the valve speed could easily be changed using a flow control valve. Electric solenoids could also be used to remotely control the valve positioning. All of the above components were assembled and incorporated into the control system. A rotary potentiometer was also installed to indicate valve position.

The gate valve on the cultivator had a hydraulic actuator built into it, but it was not in good working condition. This valve was smaller than the plug valve used at the EMS, so an electric linear actuator that could open or close the valve in a few seconds was available. The actuator was obtained and the valve modified to accept this actuator. This actuator was rated for use in wet environments, and had a built in potentiometer to provide an indication of valve position.

6.2.3 Electronic Control System Selection

Electronic control system hardware was readily available for this type of control system problem. Standard components that could survive in a manure pumping environment housed in a suitable enclosure could be used. These components are relatively easy to program, and are also easy to obtain and service. An industry standard 68HC811 microprocessor was used as the CPU and standard opto-isolators and relays were used to convey the information from the CPU to the appropriate electronic components. All of the electronics were housed in a weatherproof enclosure. Weatherproof connectors were used for all external connections.

A similar approach was used in selecting the radio control components. The radio modems chosen are designed to be used in this type of situation where they don't need their own housing, and are used as a communication tool between a stationary and remote device. They were chosen to give adequate communication range while not being so powerful that an operating license was required. The modems were housed in the same enclosure as the other electronic components. A schematic of the control system is shown in **Figure 1**.

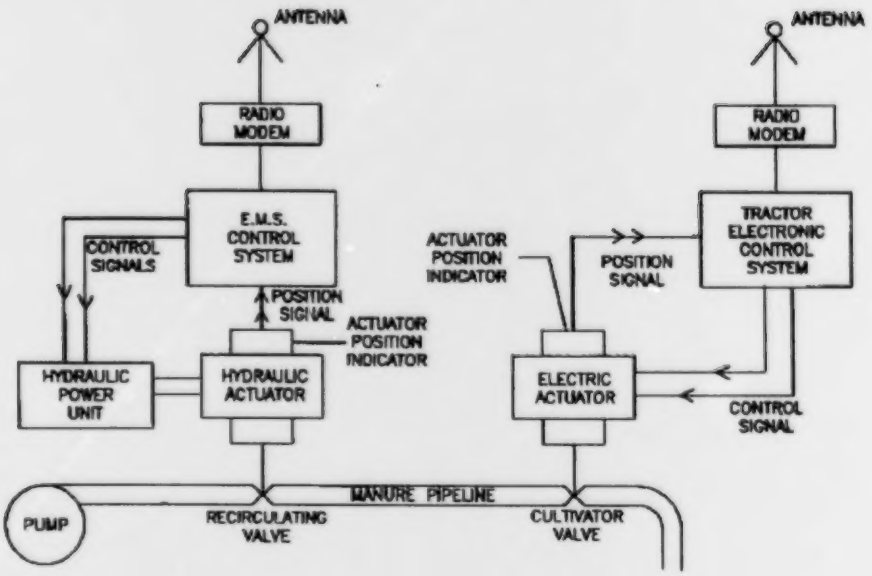

Figure 1. Control System Schematic.

6.2.4 Safety Device Selection

Because water hammer and the potential for excessive operating pressure were a major concern, several steps were taken to minimize possible system damage during initial testing. A check valve was installed immediately downstream of the main manure pump to minimize any pressure waves that may be travelling back toward the pump. The overall test strategy was to initially try long valve actuation times and then to gradually shorten the actuating time while watching for any water hammer problems.

Other measures were taken to reduce the possibility of excessive operating pressure. The overall operating strategy was to open the recirculating valve before closing the cultivator valve when shutting off the manure flow. This would ensure that the flow was never reduced to zero and the pressure would not increase beyond normal operating pressure. For the same reason when turning the manure flow on, the cultivator valve was opened before the recirculating valve was closed. A "safe" mode was designed into the control strategy, so if the controller determined that an error condition existed, the recirculating valve would open. The problem would then have to be corrected before the valve would be closed and manure flow to the cultivator resumed.

6.3 System Assembly

A schematic of the entire assembly at the EMS is shown in **Figure 2**.

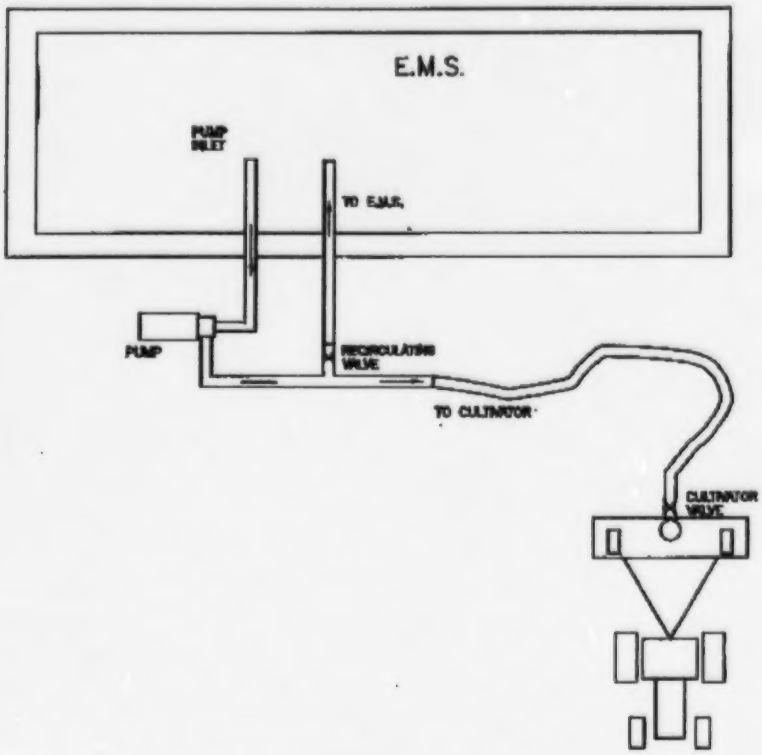

Figure 2. EMS Schematic.

All components were purchased with standard flanges and then bolted together as a unit and attached to the manure pipeline with quick couplers. This allowed for easy removal for servicing or other testing without disrupting manure pumping operations.

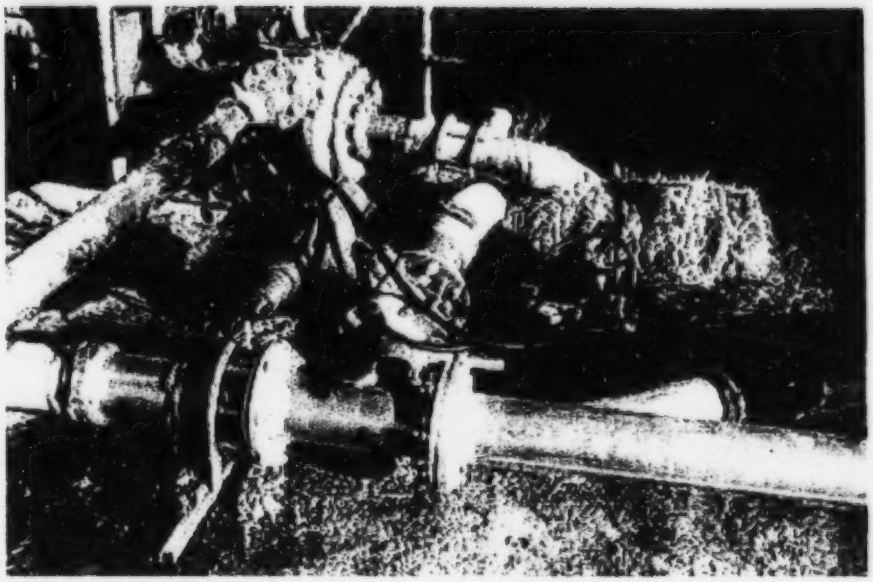

Figure 3. EMS Component Assembly.

An aluminum irrigation pipe was used for manure plumbing. The outlet of the recirculating valve was connected to a section of flexible hose that directed the recirculated manure back in to the EMS. Because no hydraulics were available as a part of the main manure pump, a separate hydraulic pump with associated pressure and flow control valves was used to control the positioning of the recirculating valve. Electrical power (12 V DC) for all EMS control system components was taken from the main manure pump engine.

The portion of the control system that was at the EMS was housed in a weatherproof cabinet. This unit included controls for system power, and local and remote control. Lights were used to indicate valve positions, operation status, and error conditions. An antenna was mounted on a stake about 20 ft. high and a cable connected the antenna to the control unit.

The tractor electronics were mounted in a separate box in the tractor cab. Switches controlled the system power and local control of the cultivator valve. An antenna was mounted on the top of the tractor cab.

The control system operated in the following manner. When the EMS unit is first turned on, the unit goes into "safe" mode (the recirculating valve open) and waits for a RF (radio frequency) signal from the tractor unit. When the tractor unit is turned on, it attempts to communicate with the EMS unit. When this communication is established, the control system positions the recirculating valve to start or stop the manure flow,

depending on the cultivator valve position. When the tractor operator moves the switch in the tractor cab to turn the manure flow off, the control system opens the recirculating valve, and when it is completely open, the cultivator valve is completely closed. When the tractor operator moves the switch in the tractor cab to turn the manure flow on, the control system opens the cultivator valve and when it is opened completely, the recirculating valve is closed completely.

The control system also incorporates a "local" mode, so that both valves could be locally manually controlled from the appropriate control box.

During all opening and closing operations, the control system monitors the valve position, and if the valve movement stopped before the valve was completely opened or closed, an error condition was set, and the control system went into "safe" mode. The error then had to be corrected and both EMS and tractor units reset before manure flow could be continued. The same was true if the RF signal was lost for too long of a time period.

Both the EMS and tractor units are continually communicating with each other to monitor switch and valve positions and confirm that the RF link is established. Any reprogramming of the control software or valve position limit settings was originally done using a laptop computer. This required computer programming knowledge, and was therefore not practical except for trained personnel. This was later changed to a system where a potentiometer in the control box was adjusted to change valve position limit settings.

6.4 Field Testing

When the complete system was assembled, some preliminary tests were done with no manure flow. The electronics in the tractor were tested independently by using a laptop computer to simulate the other half of the system. When this part was working correctly, the electronics at the EMS were also independently tested. When both halves of the system seemed to be working correctly, trials were done with the entire system without manure flow. This test revealed some problems in the programming logic, and changes to the programming were made. After the changes were complete, and the system appeared to be working without manure flow, the main manure pump was turned on and the first full scale trials began.

The first full scale trials were carried out with the hydraulic flow control on the recirculating valve set for a 20 second actuation time. At this setting, there was no water hammer in the manure pipeline, and the manure flow appeared to start and stop normally. Manure line pressure during operation was about 135 psi, and this dropped to about 45 psi when the flow to the cultivator was shut off. This pressure was sufficient to keep the flexible part of the drag hose from collapsing or twisting as the cultivator went through a 180° turn. Because all was working well, the actuation time was gradually shortened until an actuation time of 7 seconds was achieved. This was considered acceptable by the operators, as it was fast enough to not significantly affect pump out time without introducing water hammer into the manure pipeline.

During field testing, the electronic control system occasionally did not function correctly. When any type of error condition existed, such as a loss of radio contact or a valve not opening completely, the unit would go into "safe" mode, and the manure flow to the cultivator would be shut off and diverted back to the EMS. Although this prevented any damage to the manure pipeline, it disrupted manure pumping. Initial problems were diagnosed as software programming bugs, and after being corrected, the system operated more reliably.

Another problem that emerged was that it was very difficult to completely seal the linear actuator and other components on the cultivator from manure. Some manure was leaking out from the manure piping joints on the cultivator, and this dripped on to the valve actuator. Even though the actuator was rated for use in wet environments, it was almost impossible to completely ensure that no manure would enter it. When manure did enter the actuator, it resulted in incorrect valve position readings and subsequent incorrect operation. The actuator manufacturer indicated that enclosing the actuator rod in a rubber bellows would help to keep any liquid out of the actuator. This was done along with sealing the motor end of the actuator with a rubber sealing compound.

Manure migrating into unwanted areas created a problem with the valve. After a few hours of operation, the valve would not open fully. This was possibly due to manure solids leaking past the rod seal and into an enclosed chamber that was part of the valve rod support. The valve would then not open completely and the control system would recognize this as an error condition, even though manure flow was not affected much by the valve being partially closed. One option to remedy this situation could have been to dismantle the valve and clean it. This was thought to be impractical in the interest of keeping the manure pump in operation continuing. The remedy that was chosen was to reprogram the control system to recognize the valve as open fully at a different position. This was fairly simple to do, but it originally required knowledge of the control system software and a laptop computer. The incorporation of the potentiometer described at the end of Section 6.3 made this adjustment simpler.

After field testing was complete, some tests were done with the system off the cultivator to determine radio operating range. The valve and control system were set up at PAMI in Humboldt, and the tractor control box was set up in a half ton truck. The stationery antenna was mounted on a 10 ft. high mast, and the truck was driven down the road while attempting to control the valve. The valve could be operated reliably from as far away as 5 miles. This was an adequate distance, as most operators do not pump farther than 2 miles.

Refinements to the control system software were carried out to make the system more reliable and easy to use. The previously mentioned improvements to setting the valve position limits were also incorporated into the software at this time, as well as provisions to monitor manure pressure. A safety system to shut the engine off if the manure pressure was too high was also added.

7. Deviations from Project Plan

The scope of the project has not changed.

10. Equipment

Equipment purchased for this project included all electronic components, a plug valve and actuator, an electric linear actuator, a hydraulic power unit, and a check valve. This equipment is now in the possession of Big Sky Farms.

11. Project Photos

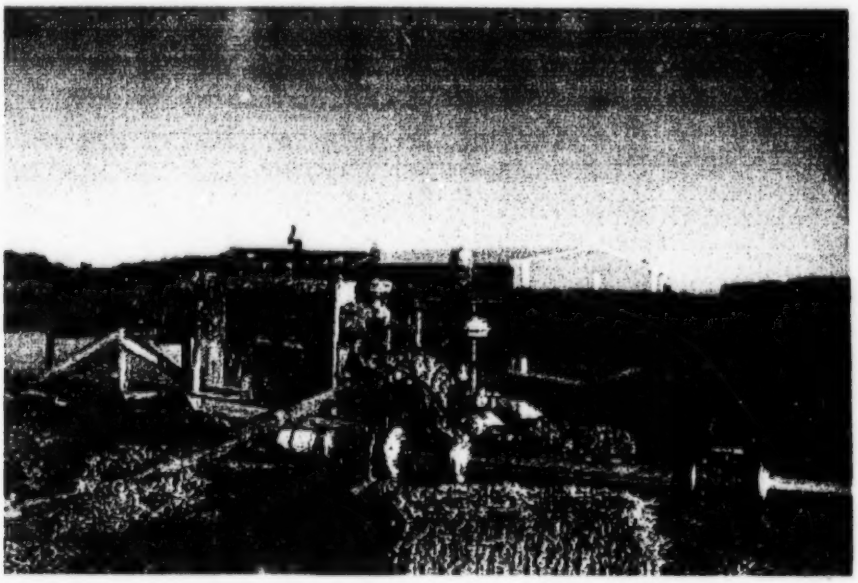

Figure 4. Pipeline Pump Unit.

Figure 5. Injection of Manure with Remote Control.

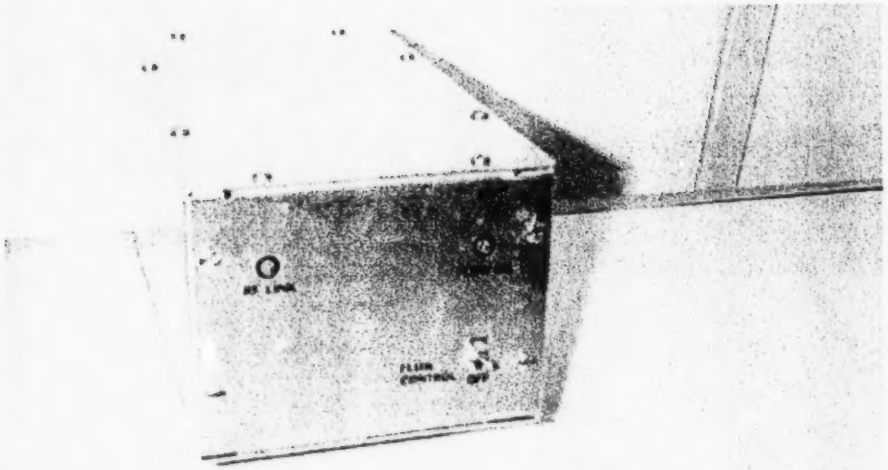

Figure 6. Tractor Control Unit.

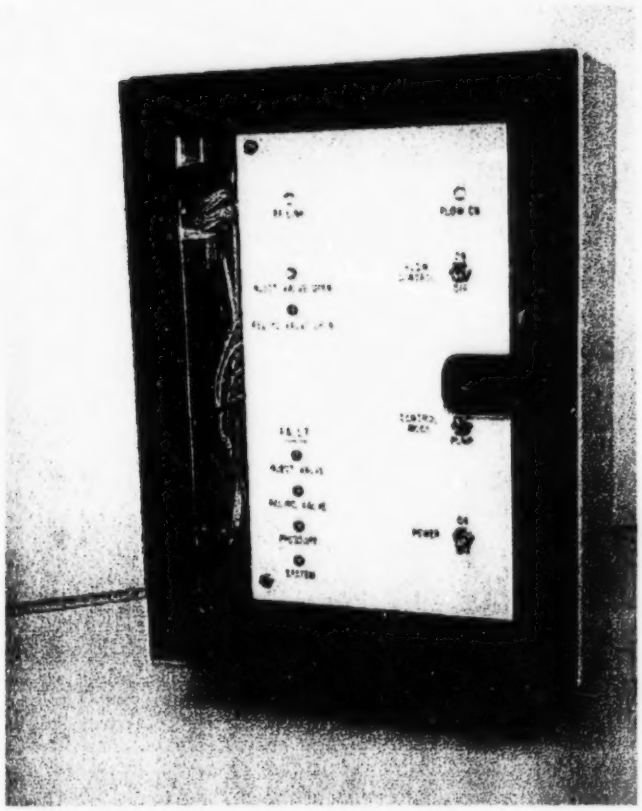

Figure 7. EMS Control Unit.

12. Acknowledgements

ADF funding will be acknowledged in all reports and at public demonstrations. This equipment was displayed during the Manure Management '99 tour in June 1999, at which time ADF funding was acknowledged.

AgriSpace Technologies developed the electronics for this project and plans to offer this system for sale to any potential users.

Appendix II

References

Crowe, T. K. Lakenman, and C. Maule. 1998. A Flow-Through Nutrient Sensor for Hog Manure. Paper No. S098-107. ASAE/CSAE Intersectional Meeting, Brookings, SD.